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# DESIGN REQUIREMENTS FOR ELECTRIC UNDERFLOOR HEAT BROODING OF PIGS 1/

By

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During the last few years a number of installations of electric and other underfloor heating systems have been made in both pen- and crate-type farrowing houses. The operation of these systems has pointed out the need for design criteria which would permit more economical construction and more efficient performance. The installation of a heating system in a concrete floor is one of the most permanent on the farmstead, permitting little alteration after construction. Therefore, a careful analysis of each installation is imperative to insure proper design.

This paper is an analytic and experimental attempt to supply some general design criteria by analyzing the basic factors influencing construction and operation.

## Heating Requirements:

Infrared lamps operate at high filament temperatures and thus supply heat by radiation to baby pigs regardless of their body temperature. In contrast, a slab with an 85° F. surface temperature cannot transfer heat to a normal pig since the surface and body temperature of the animal will be higher than that of the slab. Thus the pig is heated only by its own metabolic processes and the heated floor reduces the loss of heat by the pig. This is synonomous with the heating of houses since, unless some radiation source is used, the occupants are at a higher temperature than the ambient air and all surfaces within the house.

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2/ Located at the Agricultural Engineering Department, Purdue University, Lafayette, Indiana. Mr. Johnson is cooperatively employed by Purdue University and USDA.

The heated slab is of no value to a newborn pig until he finds it. Therefore, at temperatures below 45° F. it is advisable to use heat lamps over farrowing sows until the newborn pigs are dry and have found the heated slab (4) 3/.

We do not have sufficient information regarding the optimum surface temperature of underfloor heaters required by small pigs. A survey of several heating installations operating in Indiana and Illinois was conducted by Mr. Bruce McKenzie of Purdue University and the authors. In all instances the farmers were satisfied with the heating ability of their underfloor installations. Surface temperatures taken at the time of our visit varied from a low of 58° to a high of 87° F. Pigs appeared to be comfortable at all these installations. However, in all instances the room temperatures were above 45° F. All of these floor heating installations used circulating hot water.

In an electric-heat installation in Northern Indiana in which temperatures were sensed with thermocouples and recorded by a recording potentiometer, inside air temperatures varied between 44° and 67° F. while outside temperatures varied between 22° and 57° F. The temperatures just below the surface of the heated slabs varied between 66° and 92° F. Pigs at all times appeared comfortable, according to the operator.

These observations indicate that pigs appear comfortable over a wide range of slab temperatures. We have rather arbitrarily selected 70° to 90° F. as the design surface temperature for heated slabs without bedding.

<u>Heat Losses From Slab:</u>

Heat is lost through the slab by radiation and convection at the surface and by conduction through the sides and back. See Figure 1.

Radiation losses may be calculated by the Stefan and Boltzmann relationship which may be simplified to

$$Q_r = 0.142A\left[\left(\frac{T_s}{100}\right)^4 - \left(\frac{T_w}{100}\right)^4\right]$$

where $Q_r$ = heat transfer by radiation, BTU/hr
$T_s$ = absolute temperature of heated slab, °R
$T_w$ = absolute mean radiant temperature of room surfaces, °R
$A$ = area of exposed surface, ft$^2$

3/ Numbers in parentheses refer to Literature Cited, p. 12.

In this equation the emissivity factor is assumed to be 0.82 and the configuration factor to be 1. The unheated room temperature may be used for the mean radiant temperature with small error.

Convective heat losses are calculated by the relationship

$$Q_{cv} = hA\ (t_s - t_i)$$

where $Q_{cv}$ = heat transfer by convection, BTU/hr
$h$ = coefficient of heat transfer of convection
$t_s$ = temperature of heated slab, $^{\circ}$F.
$t_i$ = inside room temperature, $^{\circ}$F.

h may be determined (2) by $h = 0.38\ (t_s - t_i)^{0.25}$

For a slab surrounded by insulation the conductive heat losses through the back and edges of the slab are determined by the relationship

$$Q_{cond} = \frac{K}{x} A_1 (t_s - t_i)$$

where $Q_{cond}$ = heat loss by conduction, BTU/hr
$A_1$ = area of edges and back, $ft^2$
$K$ = conductivity of insulating material, BTU/hr./$ft^2$/$^{\circ}$F. per inch of thickness
and $x$ = thickness of insulation, inches
Term $\frac{K}{x}$ = conductance of a particular insulation unit, BTU/hr./$ft^2$/$^{\circ}$F.

Simplifying assumptions made are that the earth and concrete surface temperatures on the unheated side of the insulation are the same as the air temperature. These surfaces are undoubtedly at temperatures higher than air temperature, but for thin narrow slabs the error will be small and will add to the safety factor in the design.

If the heated slab is wide and is insulated by vertical insulation strips two feet in depth, then the formula above should be used only to calculate edge losses. See Figure 2. Losses through the back of the slab might then be calculated using (1)

$$Q_{ground} = 0.10\ A_2\ (t_s - t_g)$$

where $Q_{ground}$ = heat lost by conduction, BTU/hr
$A_2$ = area of back of slab, $ft^2$
$t_g$ = temperature of ground (50$^{\circ}$ F.)

Inside design temperature should be based on minimum expected inside temperature. Although the heated slabs are not designed to heat the entire farrowing building, they do contribute to the total sensible heat gains which may affect inside building temperature. For estimating purposes 60 BTU per hour may be assumed to be added per square foot of heated slab.

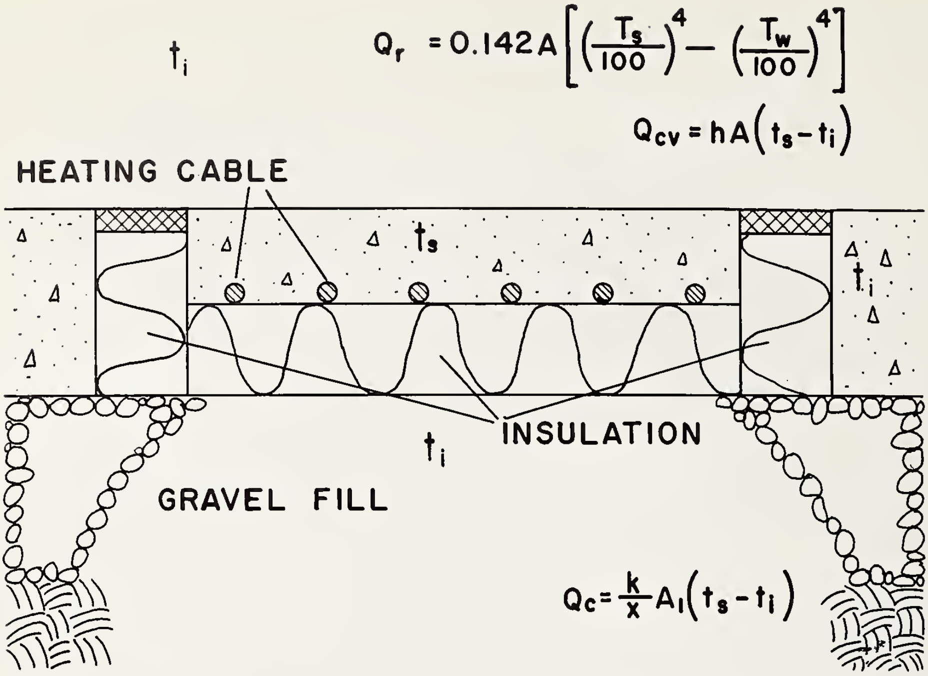


Figure 1. Heat losses from a heated slab, insulated on three sides.

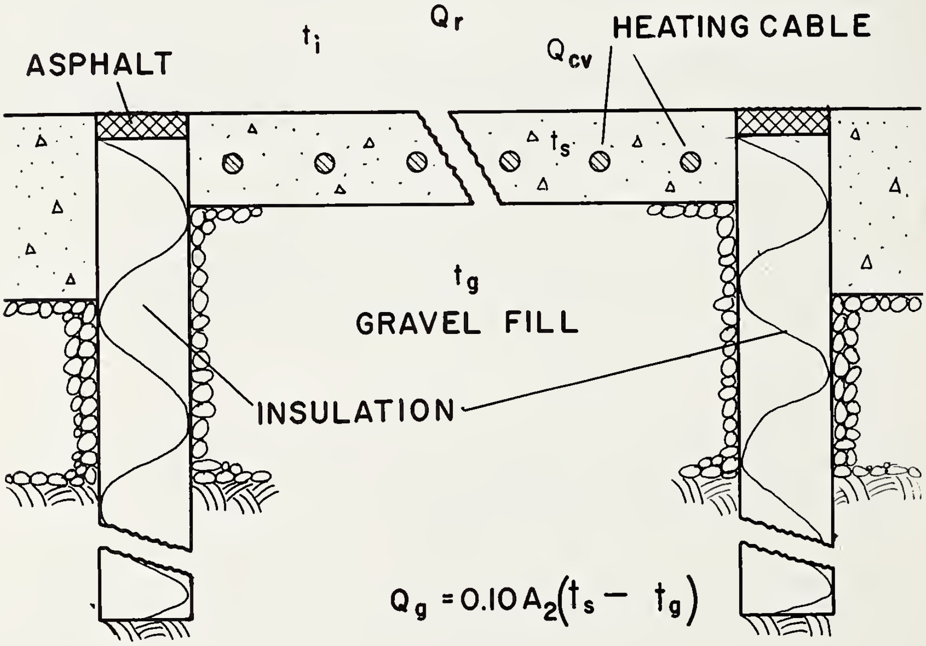


Figure 2. Heat losses from a heated slab, vertical insulation only.

Depending upon the insulation used and inside room temperature, 20 to 35 watts per square foot are generally required to maintain an 80° F. surface.

Insulation:

It is important to thermally isolate as nearly as practicable the heated slab from the adjacent floor and earth. Since the air temperature in the building may be low, heat will move horizontally through the sides of the slab and the adjacent concrete and then upward to the room or to the outdoors if the heated slab is near an outside wall. Also, since slabs are relatively narrow, the heat which moves downward into the soil need travel only a short horizontal distance until it reaches the unheated concrete and then outward or upward.

Two inches of moisture-proof perimeter-type insulation or its equivalent giving a conductance of 0.15 BTU/ft$^2$/hour/°F. or less is recommended for use on the back and edges of the heated slab. Rigid foam-type insulation materials have gained acceptance for this purpose. Insulation on the side should be brought as near to the surface as is practicable. Asphalt rather than concrete might be used to seal the top of the insulating material.[4/] Another method of insulation that may be used is to pour a 4-inch subfloor of insulating concrete, then lay the cable on the concrete and finally pour a 3/4- to 1-1/2-inch layer of wearing concrete. (See Figure 3.) A vertical insulating barrier should be placed in the wearing concrete around the heated area. However, not all heating cables are recommended for use with insulating concrete.

If heated slabs more than 4 feet in width are used, vertical insulation is more economical than insulating beneath the slab. In this method, insulation 2 inches in thickness is placed around the heated area, extending from near the surface of the floor downward 2 feet.

Perimeter insulation should also be used at the building edge, in addition to the insulation around the heated slab. A gravel fill and a moisture barrier should be placed beneath the entire farrowing floor. Roof and surface water should be directed away from the building foundation.

Area:

In farrowing crates or farrowing stalls, common practice is to heat both creep areas. See Figure 4. Creeps are generally 1 to 2 feet in width and the length of the crate, which is between 7 and 8 feet. Less than half of this space would provide sufficient heated area for all pigs of the largest litters.

Heating only one creep area is generally satisfactory but could result in small pigs not finding the heated side. A better practice would be to heat about half of the creep area on each side.

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4/ Asphalt and other petroleum products attack styrene materials.

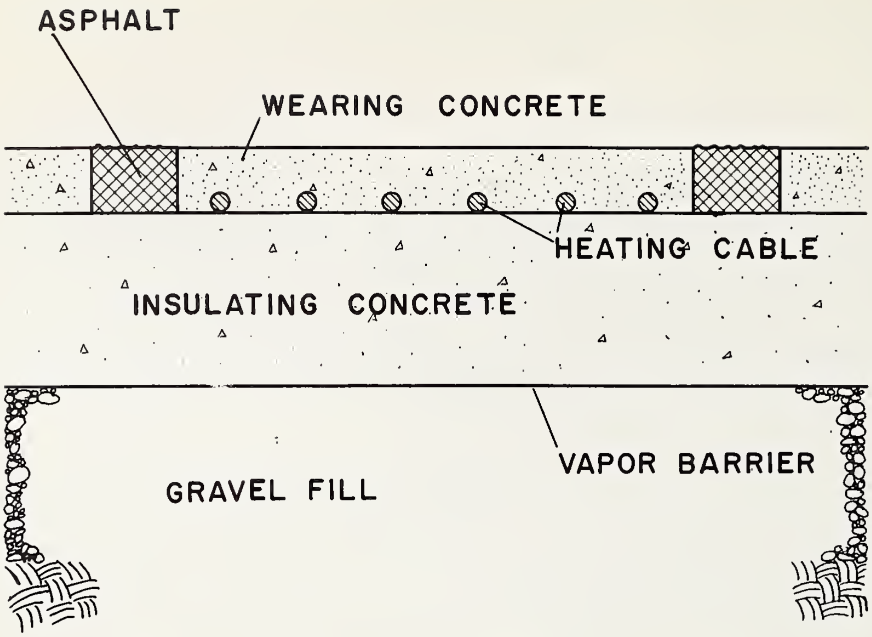


Figure 3. Insulating concrete, 4 inches in thickness, may be used under the heated area only, or under the entire farrowing house floor. A vapor barrier is important below the insulating concrete.

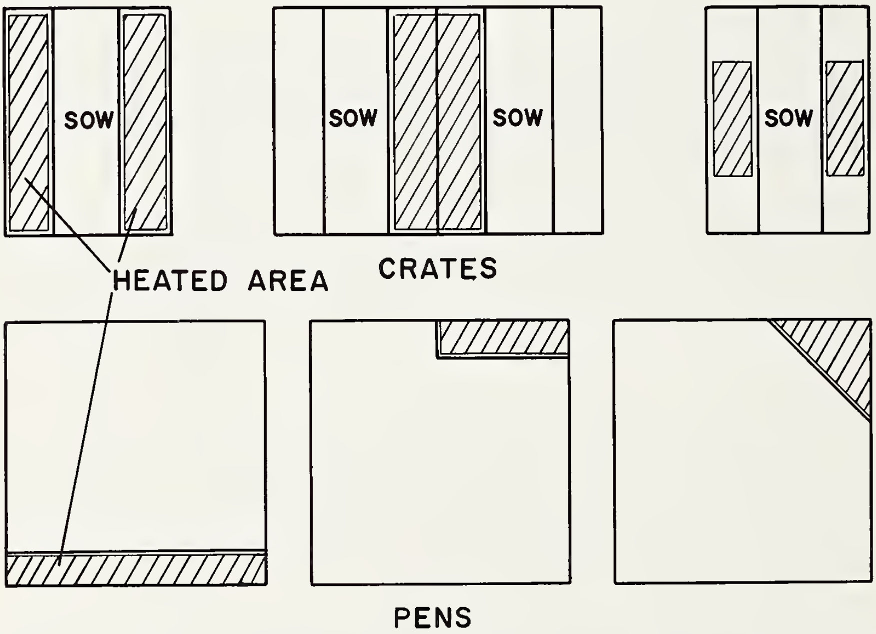


Figure 4. Heated areas may be provided in a variety of locations. Barriers must be used to prevent the sows from lying on the heated surfaces.

In pens a protected heated area about one foot in width across one end of the pen is common practice. Pens vary in width between 6 and 8 feet. Also, a corner of the pen could be fenced and heated in a manner similar to that practiced in using infrared lamps. A right isosceles triangle with 3-foot sides should be sufficient.

Floor Slope:

Every effort should be made toward having the heated area at the high portion of the pen; never have the pen drain into the heated area. It appears desirable to have the heated area 1 to 2 inches higher than the surrounding pen level.

Bedding:

A minimum of bedding, preferably none, should be used over the heated area. The floor surface should give traction but not cause skin abrasions.

Sectionalizing:

Maximum flexibility of operation and best temperature control are achieved when the heating cable of each pen is on an individual circuit controlled by its own thermostat. This is usually not economically possible, so several pens are generally controlled by one thermostat and often a number of pens are heated with an individual heating cable. Short lengths of heating cable having sufficiently high wattage densities are not commonly available for use as individual cables for small areas. It is, of course, not advisable to cut standard heating cable, since cutting the cable reduces the resistance, allowing more current to overheat the cable.

The physical layout of the pens will often dictate the method of grouping pens heated by one cable. However, in installations where the heated slab is along one side of the pen and several pens are side by side, one cable may be used for the entire group of pens. This results in the easiest and cheapest installation.

Farrowing dates in relation to available pens also should be considered. If all pens are generally in use at the same time with pigs of the same age, little would be gained by having individual-pen control. However, if the number of sows varies greatly from time to time and if the farrowing period is relatively long it would be wise to sectionalize individual pens or at least small groups of pens.

Heating Sources:

Electric heating cables, covered with various materials including lead, neoprene, rubber, nylon and thermoplastic materials, and with various ratings from about 3 to 10 watts per linear foot, are available. However, as of January 1960, no industry-wide equipment standards have yet been adopted for heating cable installations under the conditions prevailing in pig-brooding applications. The few cables carrying approval seals of Underwriters' Laboratories have either met standards for dry radiant heating installations or for snow-melting applications. Also, the sections of the National Electrical Code concerning installations of heating cables (Article 422, Sections 422-23 to 39) are primarily directed toward dry, interior radiant heating systems and outline complete installation procedures only for cables with ratings not exceeding 2-3/4 watts per linear foot. Consequently, in selecting heating cables for brooding installations, only cables specifically recommended for this purpose by the manufacturer should be used. The instructions of the manufacturer for installing and testing should be carefully followed, as well as the general provisions of Article 422 of the National Electrical Code.

Cable sets are furnished by the manufacturers complete with nonheating leads at least 7 feet in length and shall be installed in their complete length. Fused heating tapes are not recommended for burial in concrete. Lead-covered cable should be coated with hot tar or Glyptal5/ varnish or enclosed in a plastic sheath to prevent corrosion from alkali in the concrete during curing.

Several methods have been used to position the cables while the wearing surface of 3/4 to 1-1/2 inches of dense concrete is poured. These include stapling, fastening with wood strips, fastening to asbestos board backing, and other approved means. If staples are used special care should be taken to avoid damaging the insulation. Heating cable assemblies are also available. These are attached to flexible backings, which provide proper spacing and greatly reduce the labor required in installation. Cables should be positioned so that they do not cross or touch. Cables not exceeding 2-3/4 watts per linear foot may not be spaced closer than 1 inch; with cables of higher wattage a minimum spacing of 1-1/2 inches has been common practice.

Cable circuits should be checked for continuity and short circuits to ground before being covered with concrete, and again after the pouring operation is completed to determine whether damage has occurred.

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5/ Mention of trade names of specific equipment in this publication is made for purpose of identification and does not imply endorsement by the U. S. Department of Agriculture over similar equipment not mentioned.

Controls:

Underfloor electric heating requires a temperature controller to operate satisfactorily at low cost. An ideal sensing element would gain and lose heat through the same modes of heat transfer and at the same rate as the animals for which the controller is regulating the heat supply. Such a controller has been developed for chickens (5) but not, to our knowledge, for pigs.

Thermostatic controllers sensing ambient air should not be used to control the slab temperature but should be wired in series with the slab thermostat so that no heat is supplied to the slab when the air temperature is above approximately $55^{\circ}$ F. See Figure 5. Slab temperature can be controlled with a remote capillary-type controller in which the sensing bulb is located in a slight depression in the slab. See Figure 6. This method allows the controller to sense both slab and air temperatures. The bulb must be protected with a mechanical guard so that pigs cannot lie on it. Each cable may be wired through a switch or through a plug and receptacle to the thermostatically controlled line; thus in many installations only 1 or 2 thermostats are required for the entire farrowing house, yet individual pens may be cut in or out. One limitation to this system is that the pen in which the thermostat is located must always be in operation.

Interval timers are other types of controllers which may be used. These motor-operated timers turn the power on for a fixed percentage of each time cycle, depending on the setting, and may be varied for heats from about 5 to 95 percent. A time cycle of ten minutes or longer is recommended. Note that this type of control is manually set and will not compensate for changes in temperature. A proportional-time temperature controller (3) has been developed and patented which automatically varies the heat setting with temperature.

Cost:

No comprehensive study has been made of installation costs. One installation using 2 thermostats for 2 cables with 10 pens heated per cable was made for less than $200, including insulation but exclusive of the farmer's labor. This figure would be higher if individual cable were used for each pen.

This installation used 1506 kw.-hr. of energy for 20 sows and 162 pigs for the period February 1 to March 2, 1956, and 374 kw.-hr. between February 18 and March 6, 1957.

Other Underfloor Heating Methods:

A commercially available electric heater consisting of a conductive cloth sandwiched between two layers of rubber may be used in place of cable. This material may also be used as a mat on top of the floor when provisions are made to protect it from being damaged along the edges by the pigs or sow. It is available in any wattage density, in practically

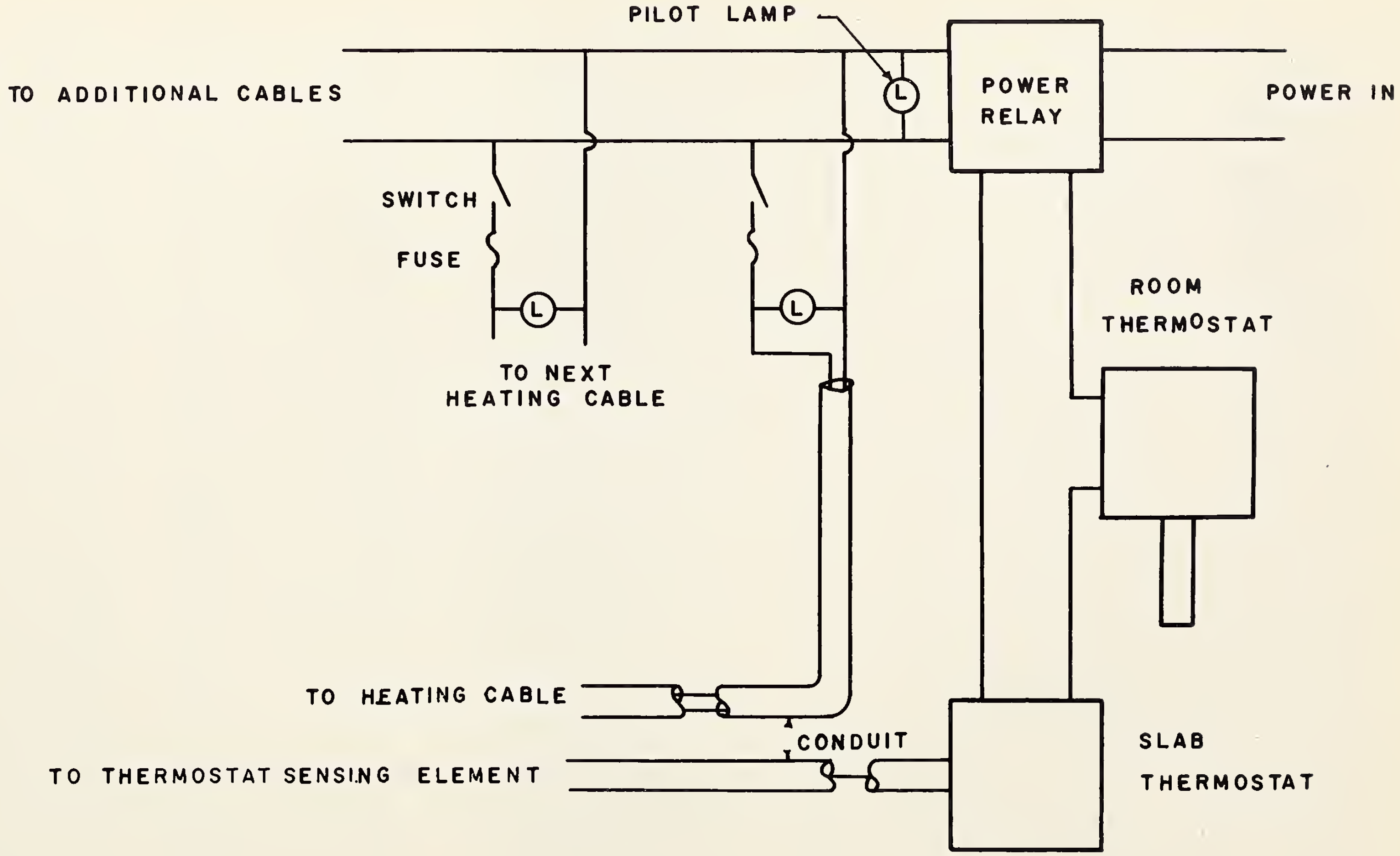


Figure 5. Schematic diagram showing connections of thermostats and cables. Power relay is not required if total connected load does not exceed smallest thermostat rating.

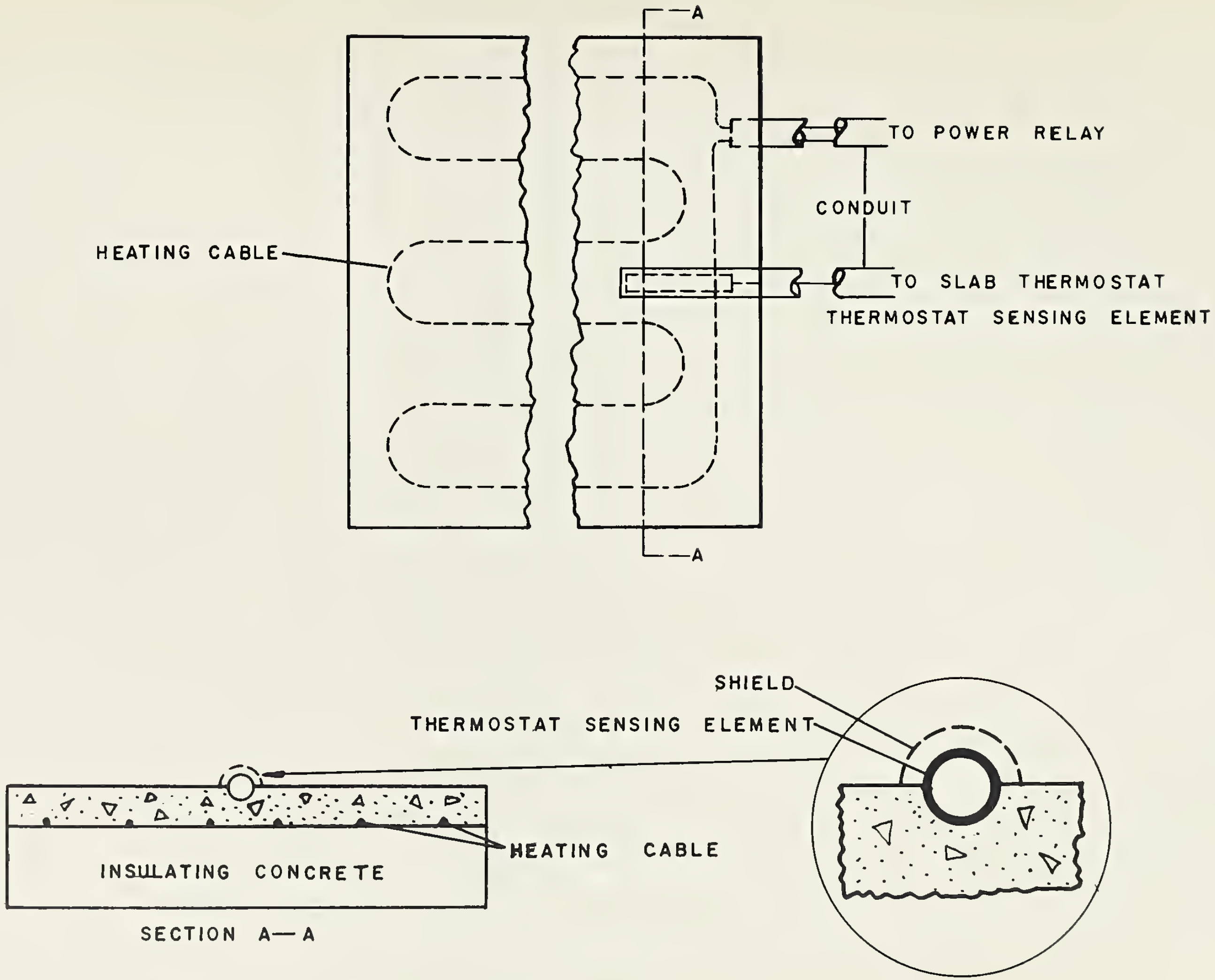


Figure 6. The power cables and slab thermostat capillary tube are protected with conduit. The slab thermostat sensing element must be shielded with a perforated guard.

any size or shape which might be needed for pig brooding. It may also be purchased in rolls and cut to length without disturbing its wattage density.

A portable water-filled heater is also commercially available which uses a submerged electric heating unit and an individual thermostat.

Permanent underfloor heating systems may also be installed using circulating hot water or hot air. Design requirements regarding heat losses from the slabs for these heating methods would be the same as for electric heaters with the addition of heat losses in the boiler or furnace and delivery pipes.

Summary:

The following steps should be followed in designing underfloor-heat installation for pigs:

1. Thermally isolate the heated slab from the unheated floor.
2. Design for surface temperature between 70° and 90° F.
3. Calculate heat losses due to radiation, convection, and conduction from slab.
4. Use as many cable sets and slab thermostats as are economically feasible to obtain minimum operating cost and maximum flexibility.
5. Install a room thermostat in series with the slab thermostats to cut off heat when all temperature is above 55° F.
6. Install cable according to the manufacturer's recommendation and rules of the National Electric Code.
7. Cover the cable with 3/4 to 1-1/2 inches of concrete.
8. Install thermostat sensing bulb in a groove in the concrete so that it senses both floor and air temperatures.
9. Use infrared lamps over sows during farrowing at air temperature below 45° F. until baby pigs learn to use the heated slab for warmth.

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